Case Study 158

Energy efficient lighting in factories

View of the packing hall

L'Oreal Golden Ltd, Llantrisant, Glamorgan

- High frequency fluorescent lighting with daylight linking cuts electricity costs and consumption by over 70%
- Overall payback of less than two years
- Low installed load of 2.1 W/m²/100 lux
- High quality task lighting
- Scheme wins top energy efficiency award

Summary

The high-quality lighting requirements for a new factory building in South Wales could have been satisfied with a basic, no-frills system. By investing a little more time on the design and money on components, however, a solution was achieved that uses the same type, size and number of fluorescent lamps. The system produces virtually the same **maintained illuminance**[1] (level of lighting), but provides a better ***quality*** of lighting and cuts electricity bills by over 70%.

Estimates indicated that electricity charges for the basic system would have been £6090/year. Actual electricity charges for the installed, upgraded system in 1991 (the first full year of operation) were £1790, a saving of £4300 or 70.6%, and this provides a payback period on the additional investment of under two years (see table 1).

Compared with the basic scheme, the installed system saves energy and costs mainly by the use of **luminaires**[2] (light fittings) fitted with electronic high frequency **ballasts**[3] and a mix of appropriate controls, in place of lower cost, conventional switch-start ballasts and manual on/off control switches.

The design was chosen as the best example of energy efficient lighting in the industrial sector and won an award in the 1991 Energy Management in Lighting Award Scheme. This scheme was organised by the Lighting Industry Federation with co-sponsors that included the Energy Efficiency Office and the Chartered Institution of Building Services Engineers (CIBSE). It has now been superseded by the Lighting Award Scheme.

Background

L'Oreal Golden Ltd manufactures and packs a range of beauty care products at its Llantrisant factory in Glamorgan. This Case Study concerns the lighting of a new packing hall at the factory, where aerosol cans are filled with the firm's products and then weighed, charged with propellant, tested, capped, coded, wrapped and palletised.

Much of the work is automated, but visual quality control checks are necessary at all stages of the process to detect any defects, including imperfect colour and print quality on the cans and packaging. Some of the machines used in the hall are tall and bulky, forming obstructions to the light, and others are fitted with transparent guards. A high **level of illuminance**[4] in the working area with good colour rendering is therefore required.

The building was still on the drawing board when the lighting system was designed. It is a single-storey, 6m-high structure with a floor area of 1800 m². There are no partitions, and the roof is flat, with five rectangular rooflights having a combined glazed area representing 10% of the roof.

To cut down the noise level, suspended acoustic planks with narrow gaps between them form a slatted false ceiling, with cut-outs beneath the rooflights. Abundant natural light enters via the rooflights, but this is concentrated in the area immediately below because its spread is restricted by the acoustic planks.

"Award-winning design of lighting system shows how costs can be cut"

BEST PRACTICE PROGRAMME

Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

Energy related savings (annual basis)				
	Installed load (kW)	Energy consumption (kWh)	Electricity cost at 3.5 p/kWh (£)	CO_2 production (tonnes carbon)**
Basic scheme*	19.88	174 000	6090	134
Installed scheme	15.12	51 000	1790	39
Savings	4.76	123 000	4300	95

* Switch-start control gear with manual controls operating continuously because of the access thoroughfare through the space.

** CO_2 (carbon dioxide) is a major contributor to global warming (greenhouse effect).

Table 1 Energy related savings

Vertical slotted windows in the south wall provide an outside view, but they are so small that their contribution to daylighting of the hall is negligible.

Working hours in the hall are from 0600 to 2200 hours, five days a week, with plant maintenance being done at the end of shifts and at weekends.

An access route connecting other parts of the factory passes through on one side of the hall, and this is open for use at all times, day and night.

Lighting requirement

For applications such as this, the CIBSE Code for Interior Lighting 1984 recommends a **service illuminance**[5] of 300 **lux**[6]. In view of possible obstructions to light caused by machinery, however, and the need for shadow-free lighting throughout the building with clear vision of the operations performed by the machines, the company increased this requirement to 400 lux.

Industrial lighting

Industrial lighting should facilitate quick and accurate work, contribute to the safety of those doing the work, and create a good visual environment. Efficient lighting is effective through being appropriate to the work performed at the particular time, and making use of available daylight.

Efficient electric lighting is seldom achieved simply by choosing the lamp which converts the most energy to light output, especially if the colour is inappropriate to the visual task. Nor is it necessarily achieved by gathering all the light output and directing this towards a horizontal plane at benchtop height. Work in factories is frequently carried out on various planes and levels. Light which reaches non-working surfaces, in particular walls and ceilings, can have the important advantage of improving appearance and vision and reducing glare.

Gains from reflected light

A colour scheme of pastel shades, applied to the machines and building interior, gives a pleasant, clean and bright appearance. Of particular importance to the lighting scheme is the light-coloured floor and walls which reflect back almost 50% and 60% respectively of the light falling on them. This high level of reflected light causes the appearance of the ceiling to remain the same, throughout the day and night, and helps to improve vision by reducing glare.

The luminaires used in this application have white enamelled reflectors which direct some 75% of the light downwards, with a broad spread light distribution that ensures good illumination on vertical, as well as horizontal surfaces.

Choice of lamp and ballast

Triphosphor fluorescent lamps[7] were chosen for this application because they provide good colour rendering and are highly efficient. Standard T8 (26 mm diameter) 1500 mm long lamps with a 58 W nominal rating are used in a total of 140 twin-lamp luminaires. These are distributed throughout the hall in the installed system to satisfy the 400 lux lighting requirement, and the same number would have been required in the 'basic' system that we use for comparison in this Case Study.

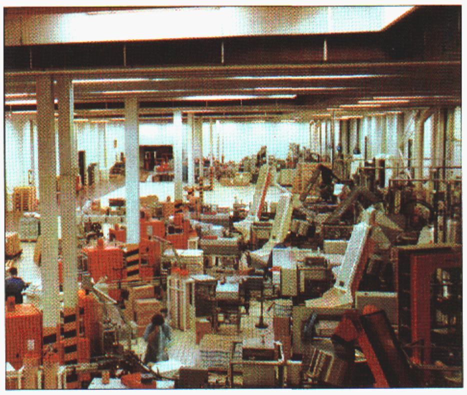
Compared with conventional **halophosphate fluorescent lamps**[7], the triphosphor type costs a litttle more to buy but produces 12% more light for a given power, and their output declines at a slower rate with age.

Discharge lamps such as these require a ballast to initiate the arc, when first switched on, and to stabilise the current after ignition. The ballast also usually corrects the **power factor**[8]. Energy is consumed by the ballast, and the efficiency of a lamp circuit as a whole depends on the total power taken by the lamp and the ballast.

A conventional ballast has a wire-wound choke that absorbs far more power than the alternative, higher-cost, high frequency electronic type that was chosen for this application.

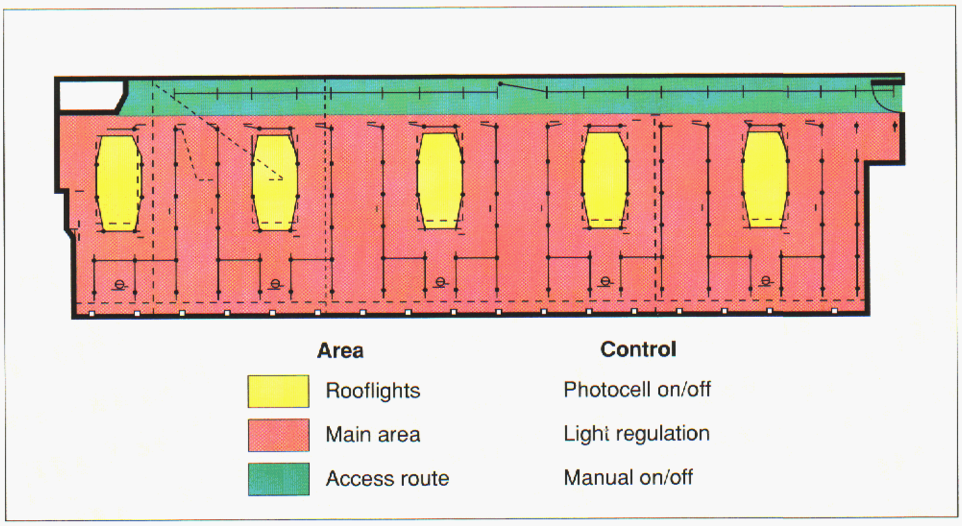
The conventional type would have been used in the 'basic' lighting system. To provide the required light output, each lamp would have had to run at 58 W, and to this must be added 13 W for losses in the ballast, giving a total load-per-lamp of 58 + 13 = 71 W, and a total load for each twin-lamp luminaire of 142 W. For a system with 140 twin-lamp luminaires of this kind, therefore, the total installed load becomes 140 x 142 W= 19.88 kW (see table 1).

The efficacy (light output per watt input) of a fluorescent tube improves with increasing frequency of the power supply. In the upgraded installed system described in this Case Study, the nominally rated 58 W lamps, running on 32 kHz high-frequency ballasts, operate at the reduced power of 50 W, and yet give approximately the same light output. (This down-rating was not a design option on this project: it is simply a standard, built-in feature of the ballast that was used.)

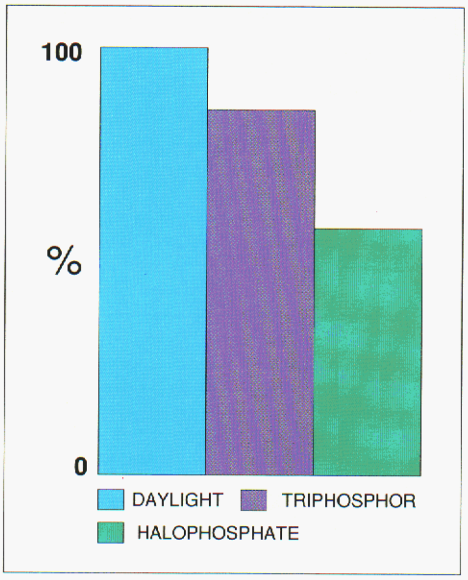


Night time view of the packing hall

Power saved in this way, combined with reduced ballast losses, increases the circuit efficacy by 24%. Two such lamps, controlled by one twin ballast, will consume 108 W, including ballast losses. The total installed load with 140 twin-lamp luminaires becomes 15.12 kW (140 x 108 W), therefore, and dividing this by the floor area (1800 m^2) gives a load of 8.4 W/m^2. This compares well with the



Plan of the packing hall



Colour rendering accuracy

target range of 12.5 to 20 W/m^2 given in the CIBSE Code for Interior Lighting (1984).

High-frequency electronic control gear offers two further advantages. One is that the ballast switches off when it detects a lamp failure, thus preventing flashing lamps and damage to the unit. Another advantage derived from the high frequency operation is the elimination of flicker, and any risk of stroboscopic effects.

Controls chosen to match daylight and usage

The luminaires are mounted in spaces between the acoustic planks, with the bottom of the reflector being level with the bottom of the planks, and around the perimeter of the rooflights. Some are fitted with self-contained emergency power supplies, and switch on automatically in the event of a mains failure.

The large rooflights indicated the desirability of a system that would take advantage of available daylight, but uneven distribution of daylight would have made a single daylight-linked control method ineffective. The area has therefore been split into zones (see circuit diagram on page 4), with the luminaires in each zone controlled by either photocell on/off, light regulation (dimming), or manual on/off switching.

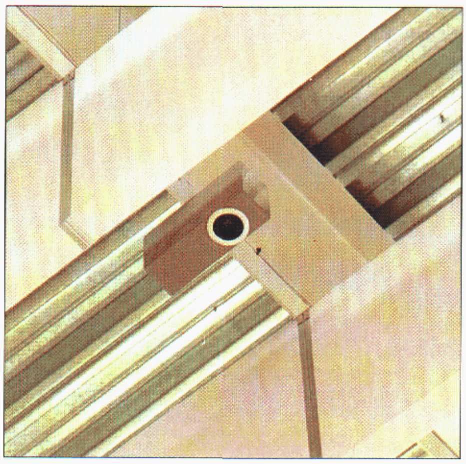
Luminaire in roof

Photocell on/off. The luminaires located within the rooflights have standard high frequency ballast fittings on a simple on/off system. Taking input from a photocell located in the rooflight, these luminaires are automatically switched off when the photocell detects illuminance levels above 1500 lux, and on again when illuminance falls below this level. Setting the switches to operate in this way, when entering daylight is two or three times greater than the system's required illuminance level, is normal practice. It has the advantage of avoiding any noticeable difference when the lights are switched on or off.

Light regulation. Working areas of the hall that are not directly beneath the rooflights are lit with dimmable high-frequency luminaires, controlled in localised groups by light output regulators. Each regulator responds to signals from a directional photocell located within the slatted ceiling, which monitors the illuminance falling upon the working plane below. As more daylight falls on the working plane, so the output of the lamps is reduced to a minimum of 25% light output. Originally the lamps switched off completely, but the minimum level was introduced when operatives complained of the annoying 'disco effect' caused by frequent on-off switching of lamps. The system maintains constant night-time illuminance on the task and smooths out short term daylight variations. Since the power consumed is directly related to the light output, corresponding energy savings are made.

Manual on/off. The access thoroughfare down one side of the factory is lit by a row of high frequency ballast fittings, with standard manual switching. Since this thoroughfare is open for use at any time, it was assumed in the costings that the luminaires serving this zone would be switched on continuously.

The scheme was fully commissioned in 1990, with the controllers set to give the illuminance required, but the design allows easy subsequent adjustment (as well as manual override) by the user to make the system either more or less sensitive to daylight.

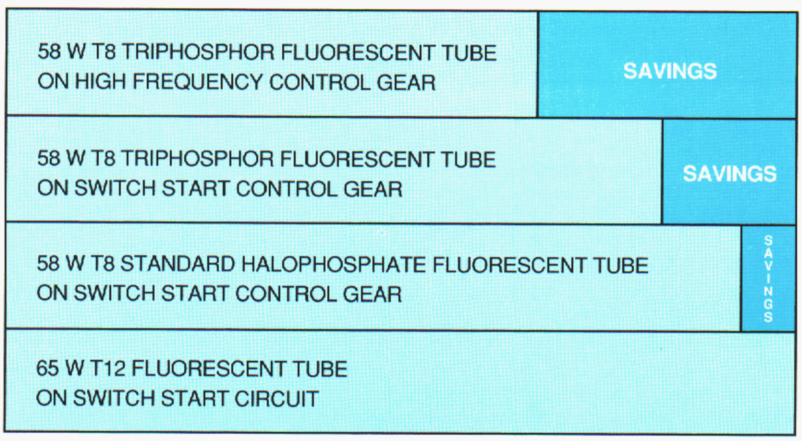


Photocell in roof

Maintaining illuminance

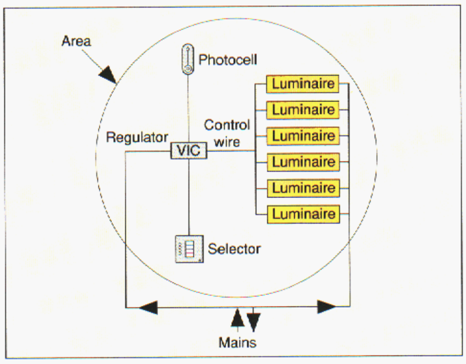
The efficiency of all lighting systems will be adversely affected by ageing of the lamps, and by accumulations of dirt on the luminaires. Maintenance programmes that include regular cleaning and replacement of the lamps are therefore extremely beneficial. At the factory discussed in this Case Study, the lamps are cleaned every 12 months, defective lamps are replaced as the need arises, and all lamps are replaced every two years.

In most lighting systems, including the basic system described above, more illuminance than necessary is provided initially to make up for losses caused over a period of time by ageing and dirt. With a regulated system controlled by photocells, however, a lower initial setting is possible because the power automatically increases to compensate for losses, thereby maintaining constant illuminance. Maximum power will be required only when maintenance is due, and maximum energy/cost savings will only be achieved when the lamps are new and clean.



Energy savings on 1500 mm fluorescent tubes in twin circuits (lumens per watt)

Efficacy of lamps and gear



Light regulation circuit diagram

Energy related savings
This Case Study illustrates the importance of choosing efficient lighting equipment and the appropriate control system.

Where large amounts of daylight are available for much of the working year the photocell controlled on/off system can help to save energy.

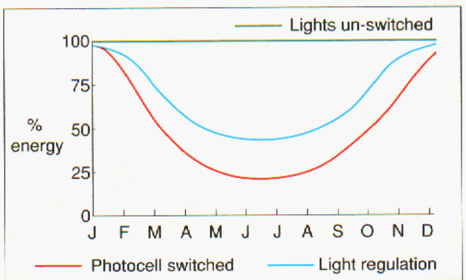
Light regulation systems are most cost-effective when lamps are lit for long periods over the working year. Advantages to be gained are dependent on the hours worked, the daylight admitted, and the triggering illuminance. They allow energy to be saved in two ways:

- by switching off lamps or regulating their output, depending on levels of illuminance provided by daylight, and
- by compensating for diminishing output from the lamps caused by ageing and dirt.

The latter can be done by reducing the power supplied to new lamps, and then gradually increasing it as the lamps' efficiency declines in order to maintain a constant level of illuminance, with minimised electricity requirements.

The use of electronic high-frequency ballasts and daylight-linked controls meant that capital cost of the installed scheme was higher than it would have been for a basic system using switch-start control gear with manual controls. However, monitored savings in electricity costs (see table 1) indicate a payback period of less than two years.

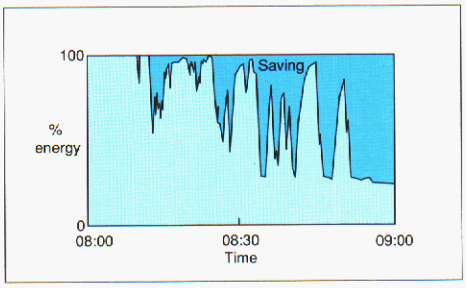
It is easy to calculate cost figures for the basic system, because the access thoroughfare requirements would probably have resulted in a manual-control lighting system being left on at all times. The annual electricity consumption is found by simply multiplying the installed load



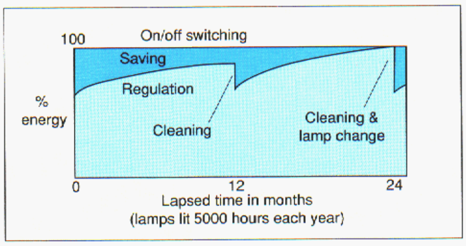
Percentage energy savings

(19.88 kW) by the number of hours in a year (8760), which gives a rounded figure of 174 000 kW.

Comparable figures could not be reliably predicted for the upgraded system before it was installed, because of variables that can affect the results for an automatically controlled system such as this. These include vagaries of the weather, and any changes the user may make after commissioning in maintenance procedures, working hours, or system control settings. However, consumption and cost figures during 1991, based on sample monitored data and therefore reflecting actual, rather than anticipated conditions, indicate that payback on investment will be achieved in under two years.



Percentage short term savings



Percentage long term savings

New recommendations and legislation
A new edition of the CIBSE Code for Interior Lighting, currently in draft form, is expected to recommend lighting levels in terms of maintained illuminance, rather than service illuminance. This will make no difference to a system such as the one described here, which has regulator controls that maintain a constant light output, regardless of daylight conditions and the affects of ageing and dirt.

Work has also begun on a number of European documents that are expected to contain new regulations and/or recommendations relating to lighting. These developments have no affect on the validity of the energy efficiency measures described in this Case Study, but they will have to be taken into account on future projects, and this may affect the energy savings that can be achieved.

Acknowledgements
This study was carried out on behalf of BRECSU, for the Energy Efficiency Office and met the requirements of L'Oreal Golden Ltd. If you adopt a similar scheme, ensure that it meets all **your** client's requirements. The assistance of the owner-occupier and of the system designer, Thorn Lighting Ltd, is gratefully acknowledged. Thorn Lighting Ltd is a member of the EEO's Making a Corporate Commitment campaign, MACC.

GLOSSARY

[1] **maintained illuminance** The mean illuminance over the relevant area at the time when scheduled maintenance calls for lamps to be replaced and/or equipment and room surfaces to be cleaned.

[2] **luminaire (light fitting)** Apparatus which controls the distribution of light from one or more lamps. This includes all parts necessary for fixing and protecting the lamps and, where necessary, additional circuit components, together with the means for connecting them to the electricity supply. Luminaire has officially superseded the term 'light fitting', which is still used colloquially.

[3] **ballast** Device connected between the supply and one or more discharge lamps to limit the current through the lamp and, either alone or in combination with a starting device, provide the necessary conditions for starting the lamp. These components, which may also include means for correcting the power factor, are collectively referred to as control gear.

[4] **illuminance** The amount of visible radiation (luminous flux) incident on a surface of unit area.

[5] **service illuminance** The mean illuminance throughout the maintenance cycle of an installation, averaged over the relevant area. The 'relevant area' may be the whole of the working plane, or it may be restricted to the area of the visual task and its immediate surround.

[6] **lux** Illuminance measured in lumens per square metre.

[7] **triphosphor and halophosphate fluorescent lamps** The glass tube of a fluorescent lamp can be coated internally with either broad band halophosphates or with narrow band phosphors, three of which are usually used together, hence the name triphosphor. Halophosphate lamps are available with either high efficacy or good colour rendering, while triphosphor fluorescent lamps combine both together.

[8] **power factor** In an electric circuit, the power factor is equal to the root mean square power in watts divided by the product of the root mean square values of voltage and current. A low power factor has the undesirable effect of increasing kVA from the power supply and reducing the useful load that can be carried by supply cables and wiring accessories. Electricity companies may therefore impose higher tariffs for installations that have a low power factor.

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